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FINITE ELEMENT MODELING TO REDUCE THE FAILURE ON REINFORCED CONCRETE WALL UNDER HARD MISSILE IMPACT

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ABSTRACT

The behavior of reinforced concrete has been investigated extensively but there have been few investigations into its transient behavior, especially under low velocity impact. This paper describes the finite element modeling and analysis of reinforced concrete wall under missile impact using ABAQUS. The results obtained from the numerical simulations have been compared with test that was carried out at Chen and May (2009) to generate high quality input data to validate numerical modeling and after that to compare them with new model which has increasing reinforcement ratio and the thickness of wall to reduce the failure of impact. The experiments were conducted on 760 mm square wall under drop-weight loads. A drop-weight system was used to drop a mass of up to 98.7 kg with velocities of up to 8.7 m per sec. The output from the test with the simulation results shows reasonable agreement when compared to the tests and for the overall kinematic response of the wall (road).

Keywords: ABAQUS.; FEM; Missile impact; Reinforced concrete.

1. INTRODUCTION

Construction of concrete used to consider various aspects of good advantages such as flexibility, high compressive strength, enough to fire and weather resistant, easy to obtain constituent materials and so forth (Mardewi J, et al., 2014).

This paper describes investigations into the impact behavior of reinforced concrete wall subjected to missile impact. While a number of studies have been carried out – both experimental and numerical for ballistic regimes; there is need of more investigations for low velocity situations, which is of most relevance to civil engineering structures (Izat, 2009). The main objective of the present study is to establish a rational procedure for the dynamic structural analysis of reinforced concrete structures under low velocity impacts. To compare with finite element analysis and with new model which has increase reinforcement ratio and the thickness of wall to reduce the failure of impact, the experimental data for the wall tested at Heriot-Watt University has been used (Chen & May, 2009). This data was produced as a result of a series of well monitored tests conducted on reinforced concrete wall impacted by missile. The test program was specifically designed to produce high quality input data for the validation of computational methods. Concrete Damage Plasticity (CDP) model has been used with appropriate parameters to model the nonlinear behavior of concrete material and elastic-plastic material which has been selected for steel reinforcement.

The finite element analysis has been carried out using ABAQUS (ABAQUS Analysis user's manual, 2013) employing different material models suitable for modeling reinforced concrete.

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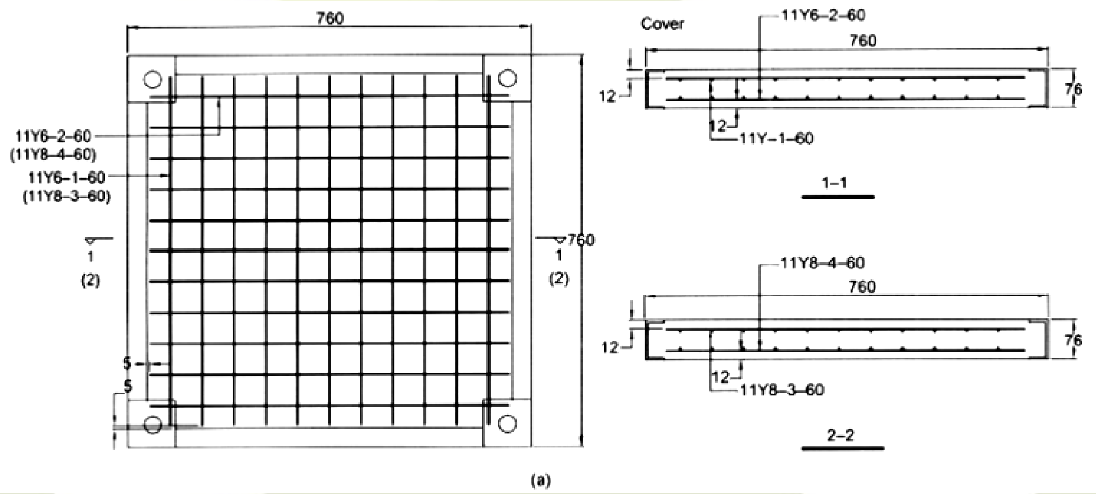
2. METHODOLOGY/ EXPERIMENT

A series of well monitored impact tests was performed by Chen and May et al. (Chen & May, 2005.2006.2009) in order to get a sound basis for verification of tools for numerical simulations. These tests have now been simulated numerically using the commercial finite element code of ABAQUS. The purpose of this study is to evaluate the ability of the chosen numerical method and material models to predict the material and structural response.

In the impact tests, four 760 mm square, 76 mm thick was tested under a missile of up to 98.7 kg with velocities of up to 8.7 m/s. The wall is shown in Figure 1. The output from the test included time histories of impact force, acceleration, strains and a video footage using a high-speed video camera which recorded the images at the rate of up to 4,500 frames per second. Further details of the tests are given in (Chen & May, 2009).



Chen and May (2009)
Figure 1 Dimension of wall tested by

2.1. Finite Element Modelling

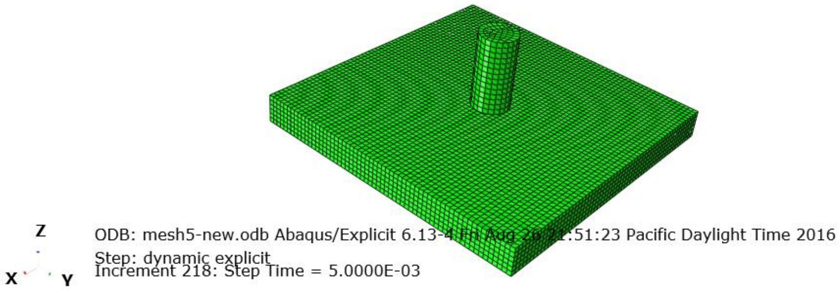
The tests have been numerically analyzed using the finite element code ABAQUS version 2013. The computer system used for these simulations is specified in Table 1.

Table 1 System specifications

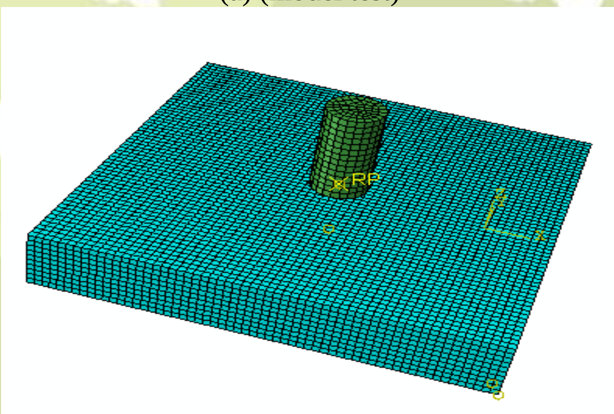
Computer	Toshiba
Processor	Pentium (R)Dual-core CPU 2.10 GHz
Main memory	4 GB
Operating system	Windows 8.1 Pro
Pre-processor software	Hyper Mesh version 8.0
Finite element analysis software	ABAQUS version 6.13-4

2.1.1. Element's Modeling of RC Wall

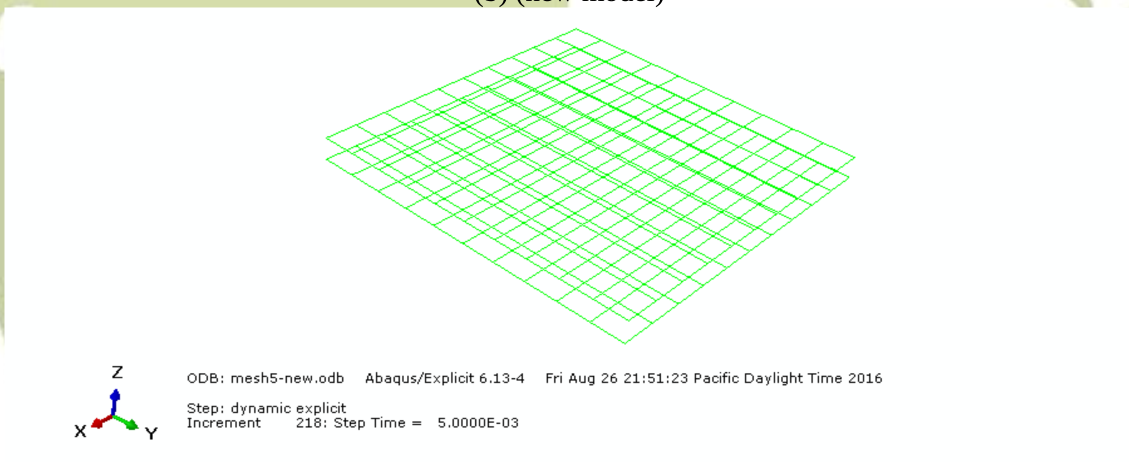
The concrete portion of the wall and impactor have been modeled by eight-nodded continuum solid elements (C3D8R) and the steel reinforcements have been modeled by two-nodded truss elements connected to the nodes of adjacent solid elements of concrete by embedded technique of FE software ABAQUS (2013). The wall has totally been fixed. The impact load (drop-weight) has been developed by continuum solid impactor with an initial velocity of 8.7m/sec.



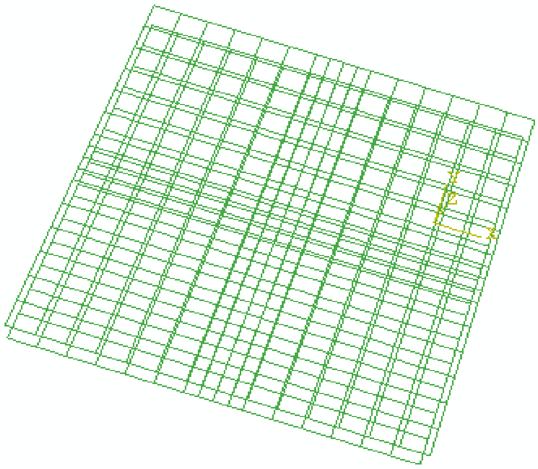
(a) (model test)



(b) (new model)



(c) (model test)



(d) (new model)

Figure 2 FE model of wall (a) and (b) complete wall with missile mesh (c)and(d) reinforcement mesh

Table 2 Mesh sensitivity

Mesh data (concrete)	Mesh model test	Mesh new model
Nodes	26047	40931
8-node hexahedron elements	21600	36000
Element sizes	12.7 mm	12.7 mm

2.2. Parts Interaction

For the present analysis of wall, surface-to-surface contact (Explicit) algorithm based on a penalty formulation and hard impact normal behavior is used for the interface between the concrete wall and the flat missile. Acceleration due to gravity is also included in the analysis. Figure 2 shows the schematic diagram of the wall.

Material property Tables 3 and 4 shows the material properties for concrete and reinforcement used for two models of the RC wall. Detail material properties with damage parameters is as used in Concrete Damage Plasticity model.

Table 3 Material Property of Concrete

Density ρ($\boldsymbol{Kgm^{-3}}$)	Modulus of elasticity E (kpa)	Poison‟s Ratio ν	Allowable Elastic stress fc (kpa**)**	Allowable Elastic Strain Ɛc(m/m)	Ultimate Stress f`c(kpa)	Ultimate Strain Ɛu (m/m)
2400	$33 * 10^6$	0.15	$29 * 10^3$	8.48×10^{-4}	$59 * 10^{\mathbf{3}}$	$0.051 * 10^{-4}$

Table 4 Material property of steel

Density ρ($\boldsymbol{kg/m^3}$)	Modulus of elasticity E (Kpa)	Poison's Ratio N	yield stress fy (kpa)	yield Strain Ɛy(m/m)	Ultimate Stress f`c (kpa)	Ultimate Strain Ɛu (m/m)
7800	$19002 * 10^4$	0.29	$305 * 10^3$	0.044×10^{-4}	579987	4.46×10^{-3}

3. RESULTS

A tow of models was created with 12.7 mm mesh sizes using two different material models for concrete wall. In this paper, only the results of two simulations were performed for wall (760 mm square, 76 mm thick) (127 mm thick for new slab) using Concrete Damage plasticity model are described. The wall was impacted by a falling mass of 98.7 kg with an impact velocity of 8.7 m/s. There was local damage on the top and bottom faces of the wall, while no perforation of the wall occurred. Figure 3 and 4 compare the simulation results using damage plasticity concrete model for wall with the tests. The comparison of damage for both top and bottom faces of the wall is given in Figure 3,4. As shown in Figure 3(a, b), the local damage on the top face of the wall is in close agreement with the experiment. There are some penetrations of the missile and 3 (b) reduces the failure more than 3(a). In Figure 4(a, b), the damage on the bottom face of the wall is compared and 4 (b) show reduced failure more than 4(a). The diameter of the damage zone in the experiment is similar to the simulations. Closer examination of results for the mesh sizes 12.7 mm, shows a small variation in the damage zones.

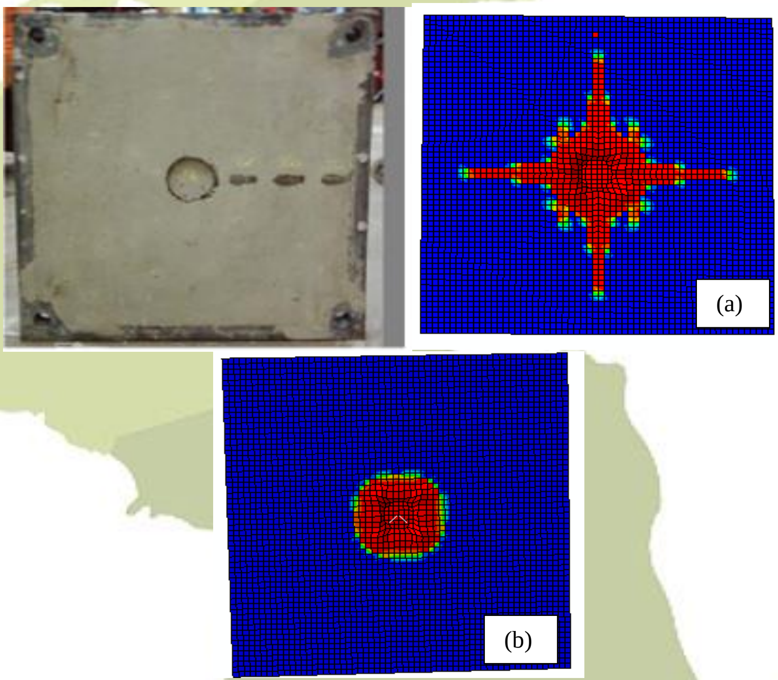


Figure 3 Comparison of simulation compression damage model test (a) and new model (b) (CPD model)

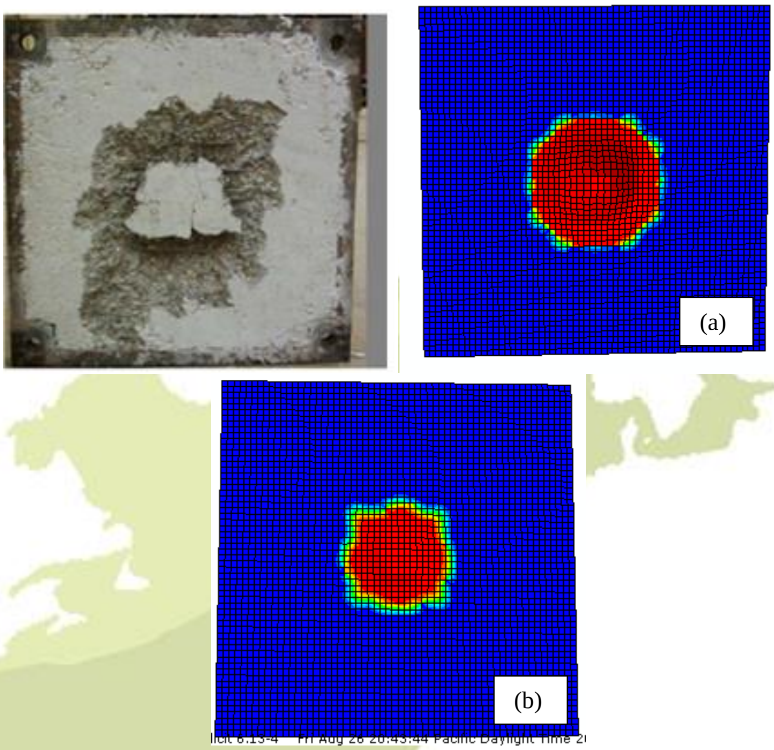


Figure 4 Comparison of simulation compression damage for model test (a) and new model (b) cracking for wall (CPD model) with mesh 12.7 mm at bottom face of wall

Figure 3 and 4 show the simulation results using Concrete damage CPD model for concrete. Failure of the concrete was defined by using compression and tension of the material. In figure 4, the comparison of test and simulation damage for wall is shown. The damage patterns at the top and bottom faces of the wall are similar to the tests. The diameter of the damage zone at the top face is in very good agreement, as in the tests which have no perforation of the wall.

3.1. The displacement history

There was no instrumentation in the tests to record the displacement histories for the wall. From the analysis, transient displacement history obtained is the center of wall to demonstrate the efficiency of the models.

Figure (5) show the transient displacement histories plotted at the center of wall (test), (new model) using Concrete damage CPD model for concrete. The analysis predicts a peak displacement of 1.09 in (27.6mm) at 5 m s for wall model test. The peak displacements for new model 0.25 in(6.35mm) at 5 m s.

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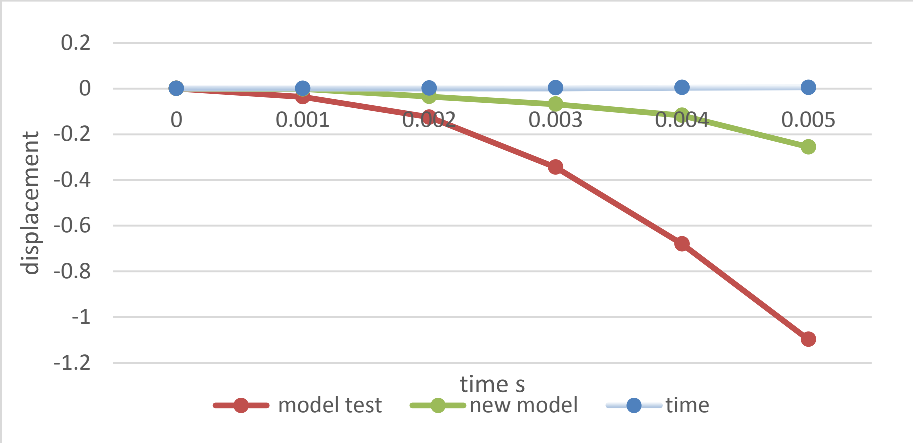

Figure 5 transient displacement history at the center of wall

Figure (5) transient displacement histories obtained from analysis at the center of wall test and new model Concrete damage CPD model for concrete.The new model shows good agreement for reducing the failure of displacement from figure (5)(6)(7).

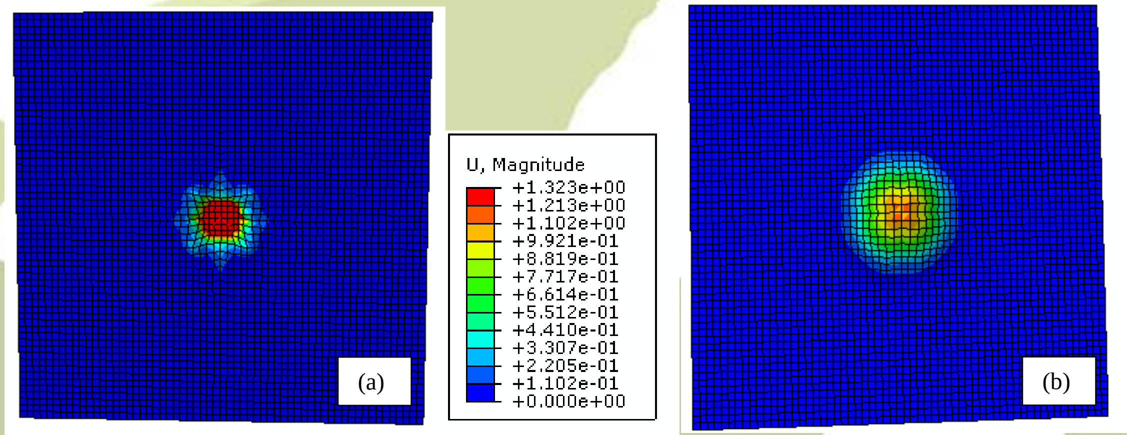

Figure 6 Displacement at the top face of wall (a) and the bottom face (b) for the model test.

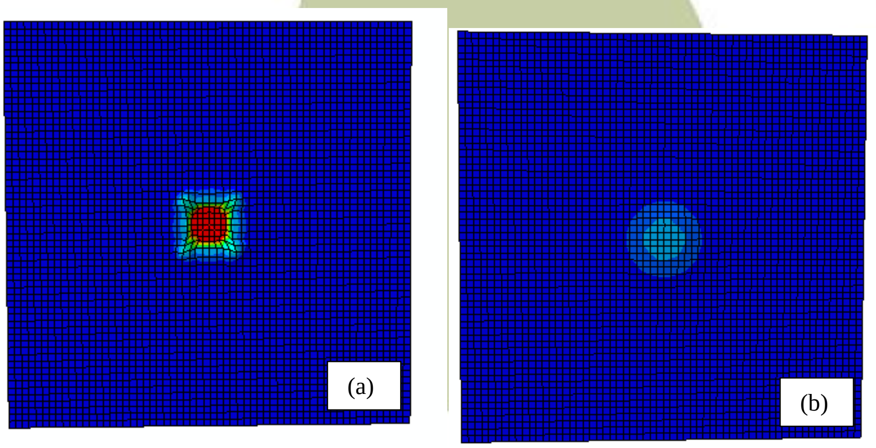

Figure 7 Displacement at the top face of wall (a) and the bottom face (b) for the new model .

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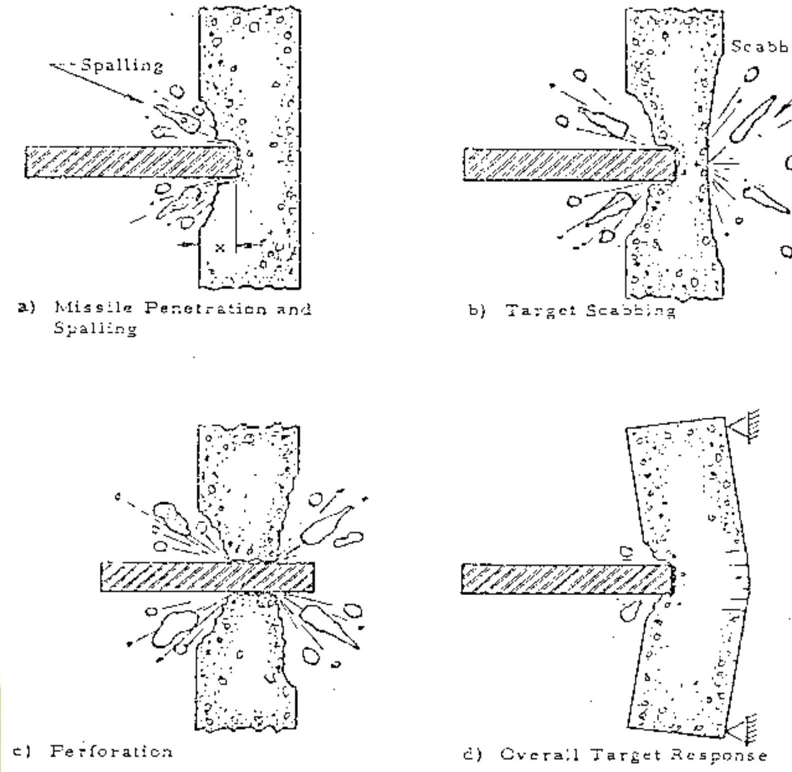

(Faiza. A, Herman. P, Wihardi.T, Rudy, 2016).
Figure 8 Missile impact phenomena

Penetration: it is the depth to which a projectile enters a massive concrete target without passing through it. The concrete is assumed not to yield (scab) on the back face. Thus, penetration is independent of the thickness of the target.
Scabbing; It is the ejection of pieces of concrete from the back of the slab opposite to the impact area, thus leaving a back crater after the impact.
Spalling: it is the ejection of pieces of concrete from the front face region surrounding the area of impact thus leaving a front crater.
Perforation: it is the depth to which projectile just passes completely through the slab causing the exit velocity of the projectile after it passes through the slab to be zero. Fig (8).

4. CONCLUSION

The comparison of crack patterns obtained using CPD concrete model with the test shows close agreement. The diameter of the penetration and scabbing zone is captured well by the simulation. The impact of force histories obtained from simulation using CDP model with the tests show good agreement. No perforations were obtained in finite element analysis which confirms to the experimental tests. The numerical analyses indicated that the overall kinematic response is captured very well. The impact behavior of reinforced concrete wall is subjected to hard missile which can be determined using the finite element procedure described. The comparison between different model test at compression damage shows no big difference. The model test has been compared with new obtained model leading togood agreement to reduce the compression damage and displacement at the center of wall (road).

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